Aircraft Electrical Systems

Princeton Airport Flying Tigers

Presented by Ernie Schirmer

Why Study Electrical Systems?

- To enable a pilot to get a better understanding of how the aircraft's electrical system operates
- ✓ which will enable the pilot to maintain and operate the aircraft more safely and
- ✓ respond more confidently to emergencies.

Learning Objectives

- Objectives
  - ✓ To present an overview of basic electrical concepts (e.g. voltage, current and resistance).
  - ✓ To review which aircraft instruments are typically electrically powered.
  - ✓ To understand the electrical system of simple aircraft
  - ✓ To review failure modes and simple trouble-shooting techniques.

Preventive Maintenance

What Maintenance Can An Owner or Pilot Perform?

- FAR 43.3(g) "The holder of a pilot certificate issued under Part 61 may perform ***preventive maintenance*** on any aircraft owned or operated by that pilot which is not used under Part 121, 129, or 135."

Based on 14 CFR Ch. 1 (1-1-03) Edition

What Maintenance Can An Owner or Pilot Perform?

- ✓ FAR 43.13(a) "Each person performing maintenance … **shall** use the methods, techniques, and practices prescribed in the current manufacturer's maintenance manual or Instruction for Continued Airworthiness prepared by its manufacturer, or other methods, techniques, and practices acceptable to the Administrator except as noted in Section 43.16."

What Maintenance Can An Owner or Pilot Perform?

- ✓ FAR 43.13(a) "He **shall** use the tools, equipment, and test apparatus necessary to assure completion of the work in accordance with accepted industry practices. If special equipment or test apparatus is recommended by the manufacturer involved, he must use that equipment or apparatus or its equivalent acceptable to the Administrator."

What Maintenance Can An Owner or Pilot Perform?

- ✓ FAR 43.13(b) "Each person … performing preventive maintenance, **shall** do that work in such a manner and use materials of such a quality, that the condition of the aircraft … worked on will be at least equal to its original or properly altered condition … "

What Maintenance Can An Owner or Pilot Perform?

- ✓ FAR 43 Appendix A
- ✓ (c) "Preventive Maintenance is limited to the following work, provided it does not involve complex assembly operations:
- ✓ (16) Troubleshooting and repairing broken circuits in landing light wiring circuits.
- ✓ (17) Replacing bulbs, reflectors, and lenses of position and landing lights.
- ✓ (24) Replacing and servicing batteries."

What Maintenance Can An Owner or Pilot Perform?

- ✓ FAR 43 Appendix A
- ✓ (30) "The inspection and maintenance tasks prescribed and specifically identified as preventive maintenance in a primary category aircraft type certificate or supplemental type certificate holder's approved special inspection and preventive maintenance program when accomplished on a primary category aircraft … "

The Paperwork

- FAR 43.9 (a) " … each person who … performs preventive maintenance … shall make an entry in the maintenance record of that equipment containing the following information:

(1) a description … of work done.

(2) the date of **completion** of the work

(3) the name of the person performing the work … "

The Panel

Mechanical Instruments

- ✓ Attitude Indicator
- ✓ Airspeed
- ✓ Vertical speed
- ✓ Directional Gyro
- ✓ Oil pressure
- ✓ Tachometer
- ✓ Suction gage
- ✓ Magnetic compass
- ✓ Stall warning

Electrically-powered Instruments

- ✓ Pitot heater
- ✓ Oil temp gage
- ✓ Exhaust gas temperature (EGT)
- ✓ Fuel gages
- ✓ Engine hour meter (“Hobbs”)
- ✓ Turn-and-Slip indicator
- ✓ Turn coordinator
- ✓ Clock

The Manual

INFORMATION
MANUAL
1980
Cessna
SALES AND SERVICE
MODEL
172N
SKYHAWK

Cessna 172N Manual

ELECTRICAL POWER SUPPLY SYSTEM MALFUNCTIONS

Malfunctions in the electrical power supply system can be detected by periodic monitoring of the ammeter and low-voltage warning light; however, the cause of these malfunctions is usually difficult to determine. A broken alternator drive belt or wiring is most likely the cause of alternator failures, although other factors could cause the problem. A damaged or improperly adjusted alternator control unit can also cause malfunctions. Problems of this nature constitute an electrical emergency and should be dealt with immediately. Electrical power malfunctions usually fall into two categories: excessive rate of charge and insufficient rate of charge. The following paragraphs describe the recommended remedy for each situation.

Cessna 172N Manual

EXCESSIVE RATE OF CHARGE

After engine starting and heavy electrical usage at low engine speeds (such as extended taxiing) the battery condition will be low enough to accept above normal charging during the initial part of a flight. However, after thirty minutes of cruising flight, the ammeter should be indicating less than two needle widths of charging current. If the charging rate were to remain above this value on a long flight, the battery would overheat and evaporate the electrolyte at an excessive rate.

Electronic components in the electrical system can be adversely affected by higher than normal voltage. The alternator control unit includes an over-voltage sensor which normally will automatically shut down the alternator if the charge voltage reaches approximately 31.5 volts. If the over-voltage sensor malfunctions or is improperly adjusted, as evidenced by an excessive rate of charge shown on the ammeter, the alternator should be turned off, alternator circuit breaker pulled, nonessential electrical equipment turned off and the flight terminated as soon as practical.

Cessna 172N Manual

If the over-voltage sensor should shut down the alternator, or if the alternator circuit breaker should trip, a discharge rate will be shown on the ammeter followed by illumination of the low-voltage warning light. Since this may be a "nuisance" trip-out, an attempt should be made to reactivate the alternator system. To do this, turn the avionics power switch off, check that the alternator circuit breaker is in, then turn both sides of the master switch off and then on again. If the problem no longer exists, normal alternator charging will resume and the low-voltage light will go off. The avionics power switch may then be turned back on. If the light illuminates again, a malfunction is confirmed. In this event, the flight should be terminated and/or the current drain on the battery minimized because the battery can supply the electrical system for only a limited period of time. If the emergency occurs at night, power must be conserved for later use of the landing lights and flaps during landing.

Electrical Concepts

Electrical Units of Measure

- ✓ **Voltage** (pressure)
  - ➢ unit of measure is the **Volt**
- ✓ **Current** (flow)
  - ➢ unit of measure is the **Ampere (amp)**
- ✓ **Resistance** (friction)
  - ➢ unit of measure is the **Ohm**
- ✓ Power (force)
  - ➢ unit of measure is the **Watt**

Electrical Symbols

- ✓ **Voltage**
  - Voltage symbol is traditionally "**E**" for **E**lectro**M**otive **F**orce (**EMF**)
- ✓ **Current**
  - Current symbol is traditionally "I" for **I**ntensity
- ✓ **Resistance**
  - Resistance symbol is "**R**" in equations and the Greek symbol omega Ω for values
- ✓ Power
  - Power symbol may be "**P**"ower or "**W**"atts

The Equations

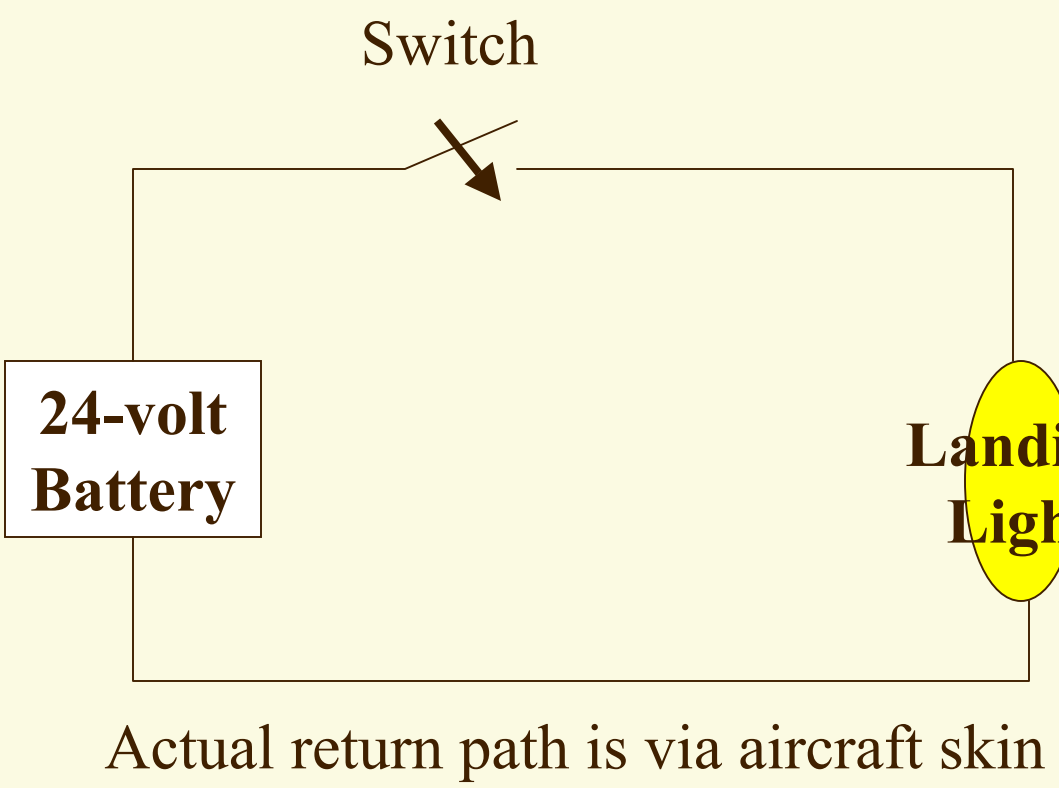
$$E = I*R$$

Voltage = Current times Resistance

$$P = E*I$$

Watts = Voltage times Current

Landing Light Problem



What is the resistance (in ohms) of the landing light?

What is the power (wattage) of the landing light?

Landing Light Resistance Calculation

$$E = I*R$$

$$24 = 9*R$$

$$24/9 = 9*R/9$$

$$2.7 \text{ ohms} = R$$

The resistance of the landing light is 2.7 Ω

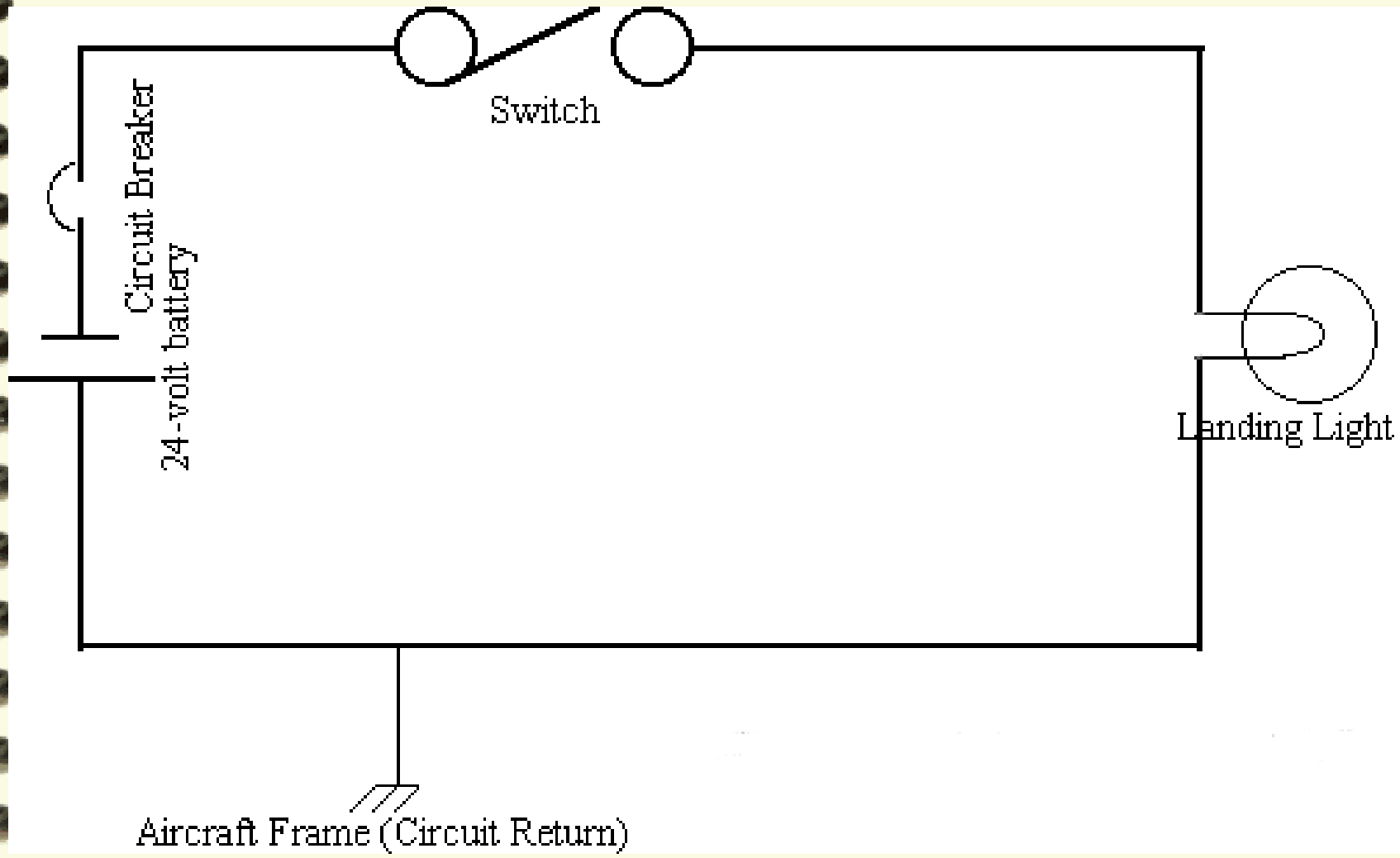
Landing Light Power Calculation

$$P = E*I$$

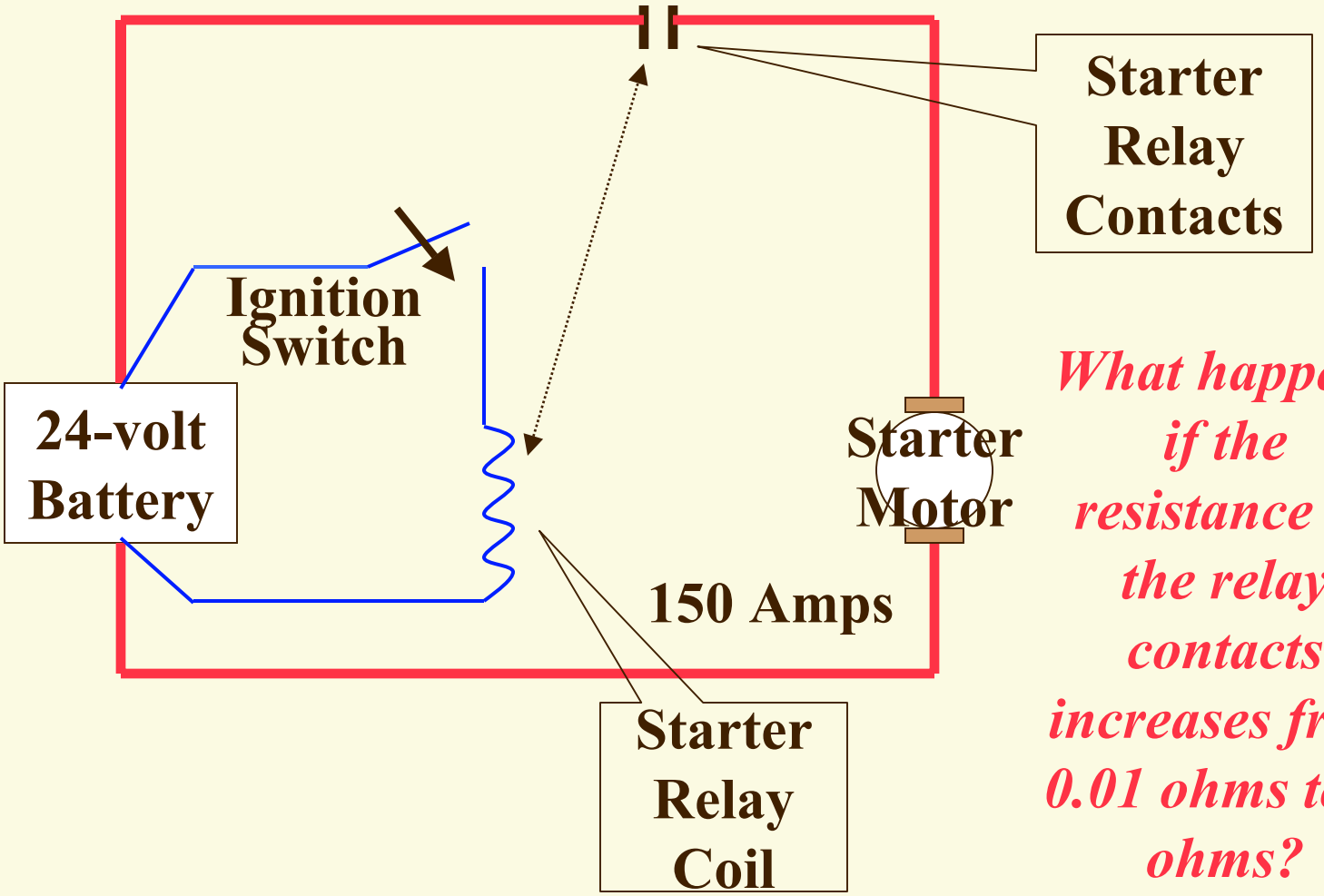
$$P = 24*9$$

$$P = 216 \text{ watts}$$

Landing Light Schematic



Starter Motor Problem



What happens if the resistance of the relay contacts increases from 0.01 ohms to .1 ohms?

Starter Motor Voltage Drop Calculation Part 1

$$E = IR$$

$$E = 150*0.01$$

$$E = 1.5 \text{ volts}$$

24 - 1.5 = 22.5 volts

available to

starter motor

Starter Motor Voltage Drop Calculation Part 2

$$E = IR$$

$$E = 150 * 0.1$$

$$E = 15 \text{ volts}$$

24 - 15 = 9 volts

available to

starter motor

Starter Motor Power Calculation

P = E*I

P = 24*150

P = 3,600 Watts

746 watts = 1 horsepower

3,600 watts = 4.83 HP at 100% efficiency

What Power Does It Take?

- ✓ Nav/Comm
  - ~ 1 amp receive
  - ~ 3 amps transmit
- ✓ Transponder
  - ~ 2 amps
- ✓ ADF
  - ~ 1 amp

What Takes The Most Power?

- ✓ Heating loads (typically continuous)
  - Pitot heater (~ 3 amps)
  - Windscreen heater
- ✓ Motor loads (intermittent)
  - flaps (~ 9 amps)
  - landing gear
- ✓ Incandescent lamps
  - landing light (~ 9 amps)
  - position lights (~ 2.5 amps)

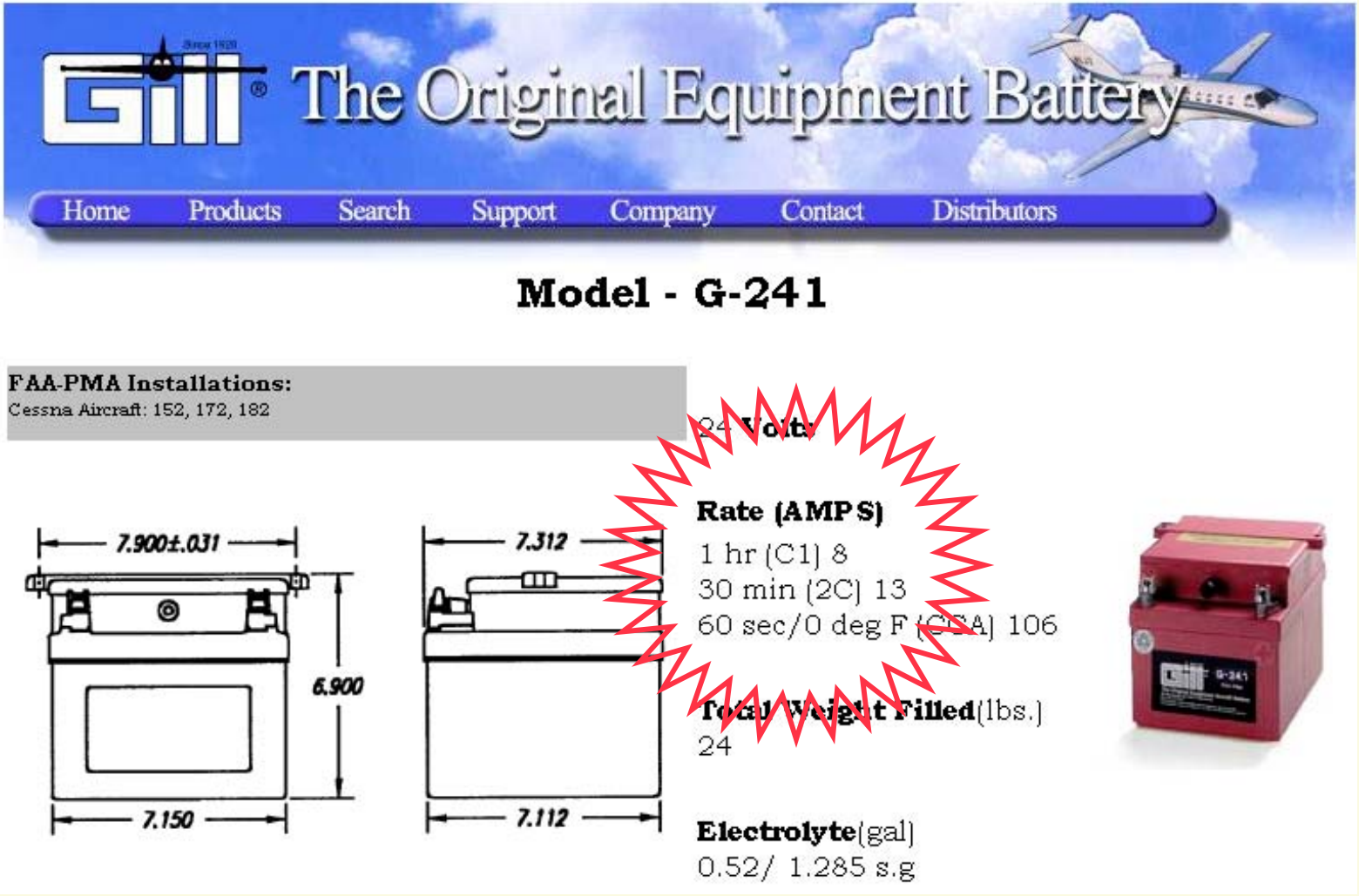
Aircraft Batteries

CONCORDE
Valve Regulated Sealed Lead Acid Aircraft Battery
AT ANY ALTITUDE
NON SPILLABLE
OR ANY ATTITUDE
Valve Regulated Sealed Lead Acid Batteries
FEATURES
• Real aircraft quality terminals, no more lawn and garden tractor types!
• New patented copper alloy internally threaded terminals.
• New brass terminal bolts with conical silicon bronze lock washers.
• Recommended 70-inch pound terminal torque.
• More than 20% higher capacity than the original RG24-11 model.
• Molded carrying or lifting handle.
• Fully aerobatic sealed construction - no spillable electrolyte or flammable gas emissions.
• FAA-PMA
Concorde's new RG24-15 brings new levels of performance as the most powerful battery available to replace the vented CB24-11 aircraft battery.
The RG24-15 model has been completely redesigned with larger positive and negative plates for more capacity and greater starting power even at sub-zero temperatures.
Please visit our Web-site @ www.concordebattery.com
...The heart of your system.®
CONCORDE
CONCORDE BATTERY CORPORATION
2009 San Bernardino Rd., West Covina, CA 91790
Phone 626-813-1234 Fax 1-800-237-4209
RG-2415

Batteries:
Failure Mode Analysis

- ✓ Mechanical
  - Vibration
- ✓ Thermal
  - Heat
- ✓ Chemical
  - Normal chemistry of charge/discharge cycles
- ✓ Electrical
  - Deep cycling
  - Overcharging

Typical Cessna Batteries



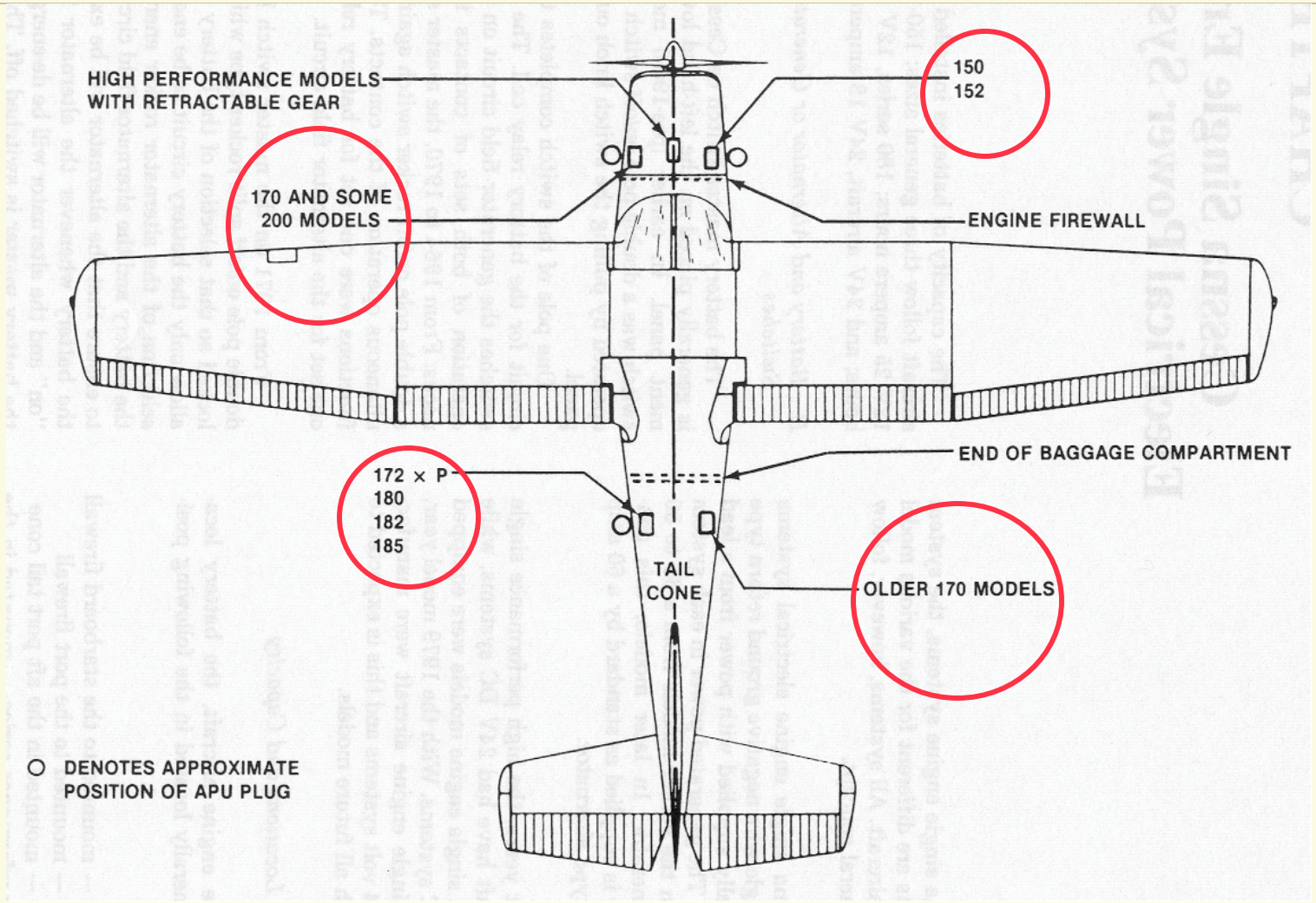
Typical Cessna Batteries

Spill-proof Vented Battery Cap

Typical Cessna Battery (Gill)

- ✓ Unsealed wet lead-acid with non-spill vent caps (***not*** a "maintenance-free" battery).
- ✓ Consists of multiple 2.1 volt cells connected in series
  - 12 cells for 24-volt batteries
- ✓ Requires regular maintenance
  - check specific gravity (Gill = 1.285)
  - add distilled water as needed
- ✓ **HEAT** and thermal cycling are a battery's worst enemies.

Where's The Battery



What's The Voltage?

"Electrical energy for the aircraft is supplied by a **28-volt**, direct-current, single wire, negative ground electrical **system**. A **24-volt battery** supplies power for starting and furnishes a reserve source of power in the event of alternator failure. An engine-driven alternator is the normal source of power during flight …"

- 28 volts = nominal system voltage
- 24 volts = nominal battery voltage

Why 24 Volts vs. 12 Volts?

- **Power (watts) = voltage * current**
- Assume a load of 760 watts.
- 760 watts = 12 volts at 60 amps.
  - Requires #6 AWG copper wire.
- 760 watts = 24 volts at 30 amps.
  - Requires #10 AWG copper wire.
- The smaller wire is cheaper, lighter in weight and easier to handle.

What's The Capacity?

- ✓ The battery should be sized* to supply the essential load (current) for 30 minutes**
- ✓ At the end of 30 minutes a 12-volt battery will discharge to 10.5 volts.
- ✓ At then end of 30 minutes a 24-battery will discharge to 21 volts.

* Capacity is a function of surface area.

** Batteries ratings are based on 25° C (77° F)

How Long Will It Last?

- A battery's discharge curve is **not** linear.
- A battery rated at 36 ampere-hours (7.2 amps for 5 hours) will not deliver 36 amps for 1 hour or 1 amp for 36 hours.
- The amount of useful remaining charge in the battery increases at a rate higher than the proportion of load reduction. For example, if the load is cut in half, the battery should last more than twice as long.

Should You Jump A *Dead* Battery?

- ✓ A battery that is discharged to the point where it can not crank the engine should not be jumped for two major reasons.

1. A **badly** discharged battery is not airworthy because it will not have the reserve capacity to operate electrical equipment that exceeds the capacity of the aircraft alternator.
2. High charging currents will damage the battery and cause premature failure.

Charging A Battery

- The main points of consideration during a battery charge are excessive battery temperature and violent outgassing. Under a reasonable rate of charge, the battery temperature should not rise over 115-125° F, nor should gassing be so violent that acid is blown from the vents.

Battery Protection: *Flyable* Aircraft Storage

- ✓ Defined as a maximum of **30** days of non-operation and/or the first 25 hours of intermittent engine operation.
- ✓ No special precautions required to protect battery unless it will be subjected to excessive heat or cold.

Battery Protection: *Temporary* Aircraft Storage

- ✓ Defined as a maximum of **90** days of non-operation.
- ✓ Remove battery from aircraft and store in a cool, dry place.
- ✓ Cessna Service Manual note:

"The aircraft battery serial number is recorded in the aircraft equipment list. To assure accurate warranty records, the battery should be reinstalled in the same aircraft … "

Battery Protection: Indefinite Aircraft Storage

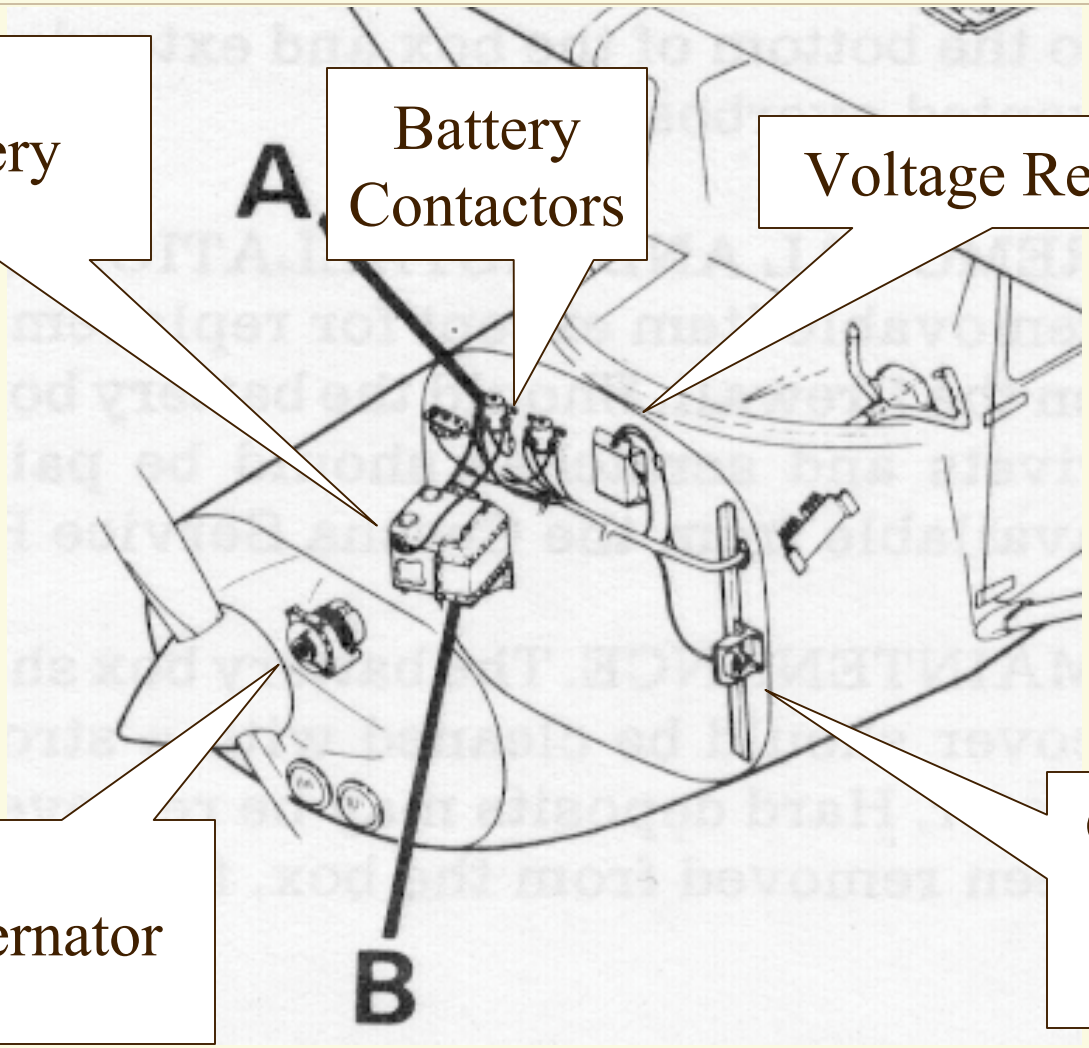
- ✓ Defined as non-operational status for an indefinite period of time.
- ✓ Based on definition of “temporary storage”, “indefinite storage” would appear to mean more than 90 days of non-operation.
- ✓ Remove battery from aircraft and store in a cool, dry place.

Charging Circuits

Charging Circuit:
Failure Mode Analysis

- ✓ **Generator/Alternator Failure**
  - Broken Drive Belt
  - Generator: Brushes
  - Alternator: Diodes
- ✓ **Voltage Regulator**

Where's The Alternator?



Battery

Battery Contactors

Voltage Regulator

Alternator

Ground Power Plug

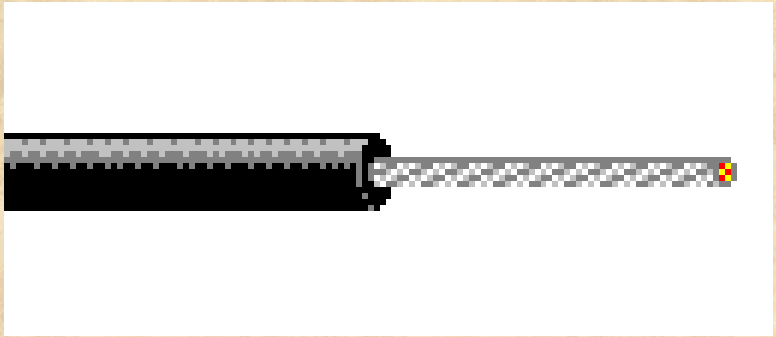
Typical Cessna Alternator

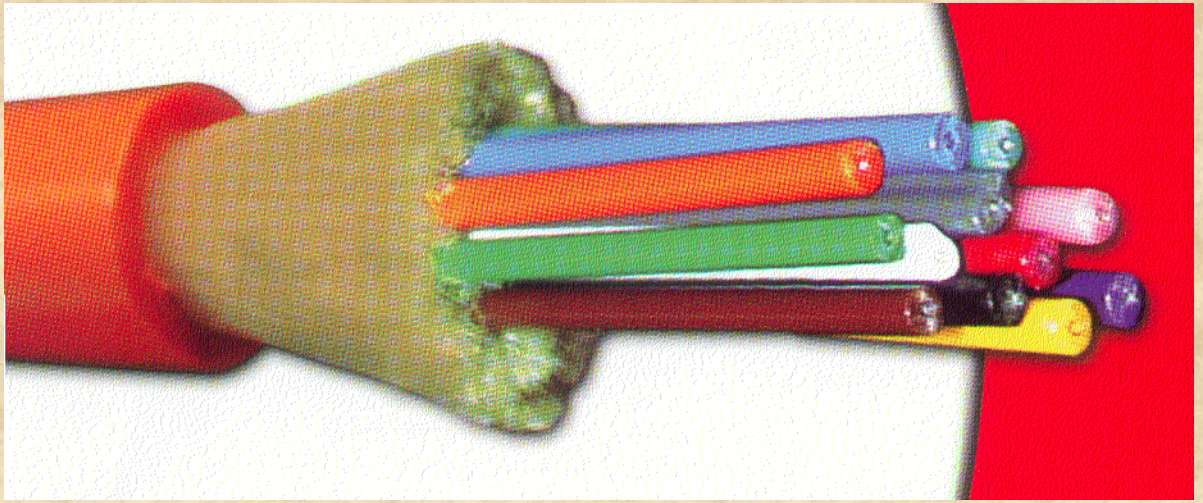
- ✓ Rated at 60 amperes at 28 volts
  - – 29.4 volts maximum under normal conditions
- ✓ Field excitation provided by battery
- ✓ Master switch is split
  - – BAT half
  - – ALT half
- ✓ Turning off the ALT half of the master switch takes the alternator off-line.

The Master Switch

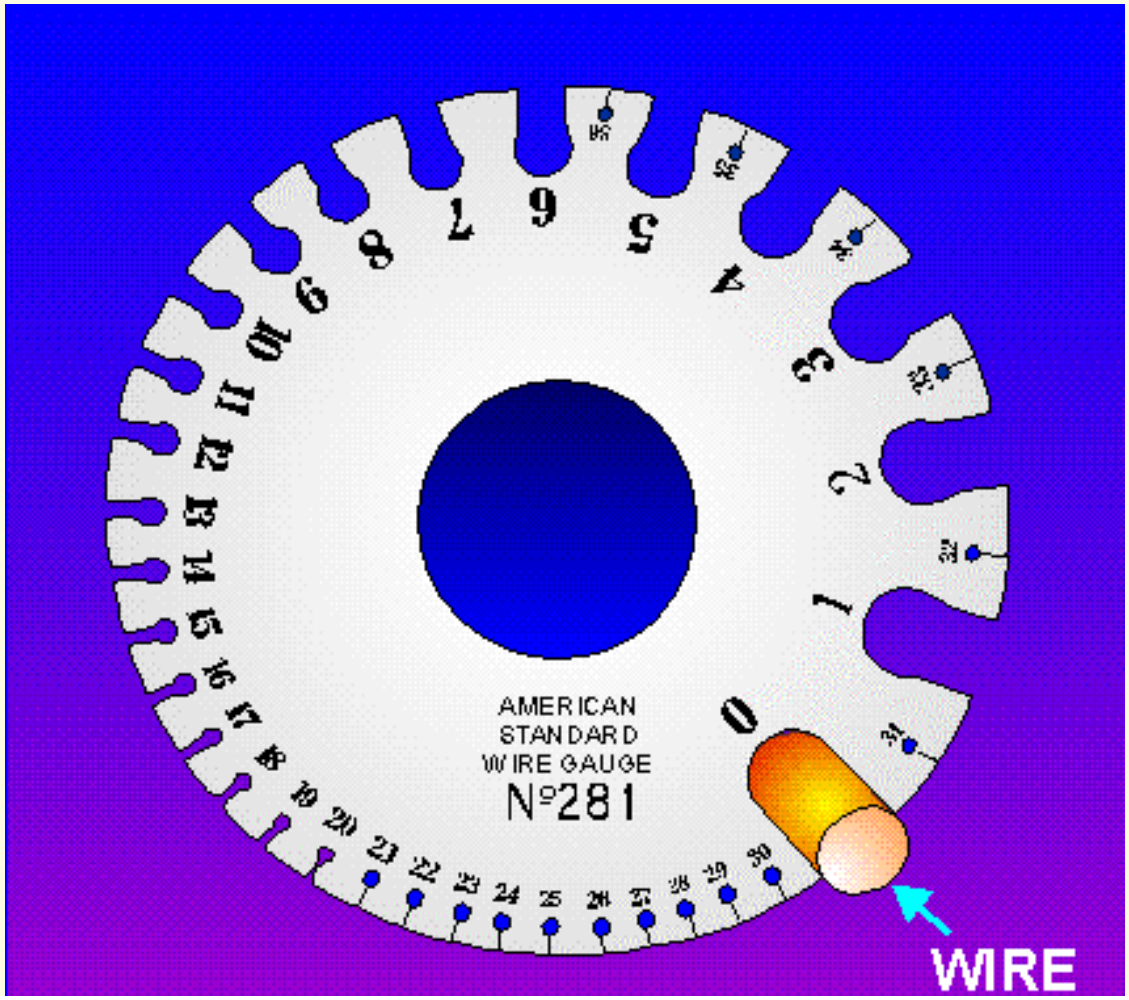
The split master switch " … allows the battery to be on-line without the alternator, however, operation of the alternator without the battery on the line is not possible."

Aircraft Wiring





Wire Sizes
American Wire Gauge (AWG)



The smaller the number, the larger diameter of the wire

Aircraft Wire and Cable

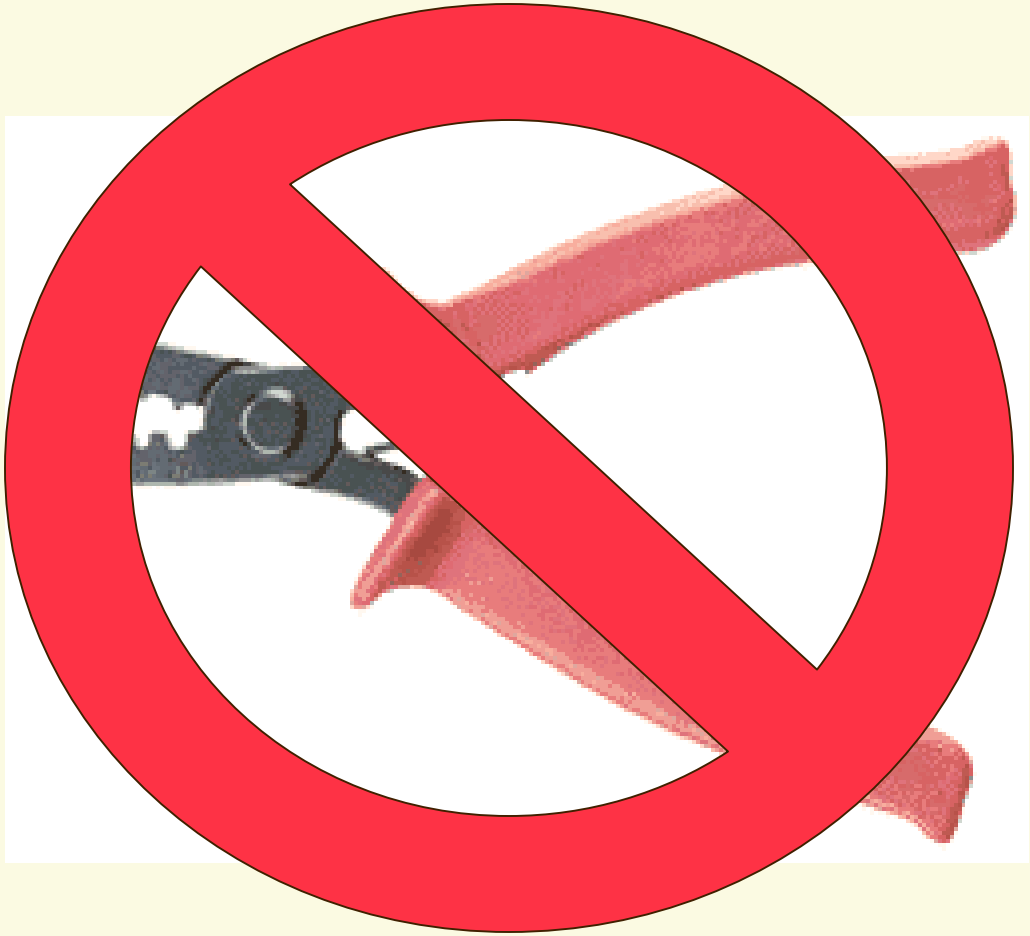
- ✓ You can't get it at Home Depot.
- ✓ MIL-W-22759/16
  - general signal and power
- ✓ MIL-W-22759
  - **s**evere **w**ind **a**nd **m**oisture **p**roblems (SWAMP)
  - wheel wells, flap areas
- ✓ MIL-W-5088L
  - approved aircraft wire types

Aircraft Wire and Cable

- ✓ Stranded cable is used to withstand vibration.
- ✓ Wire smaller than #20 AWG (American Wire Gage) must have extra support clamps, be bundled with at least two other wires and have extra support at terminations.

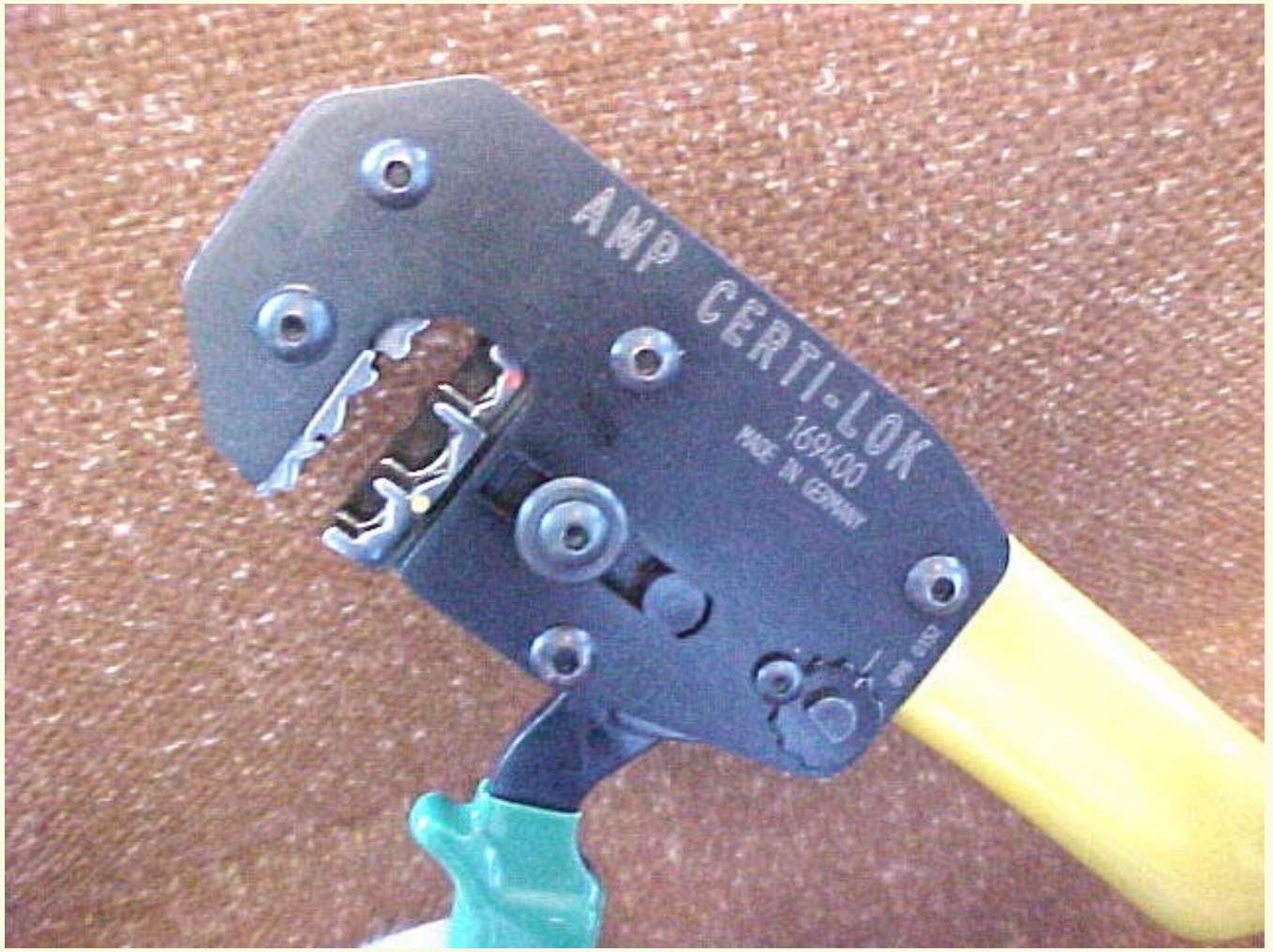
Wire Terminations

Handyman Crimp Tool

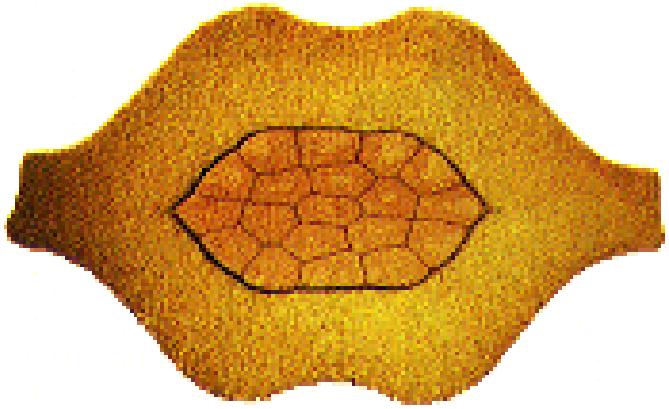


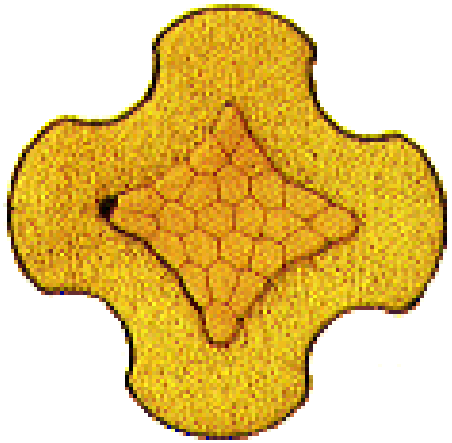
Controlled-Cycle Crimp Tool

Controlled-Cycle Crimp Tool



Crimp Lug Termination

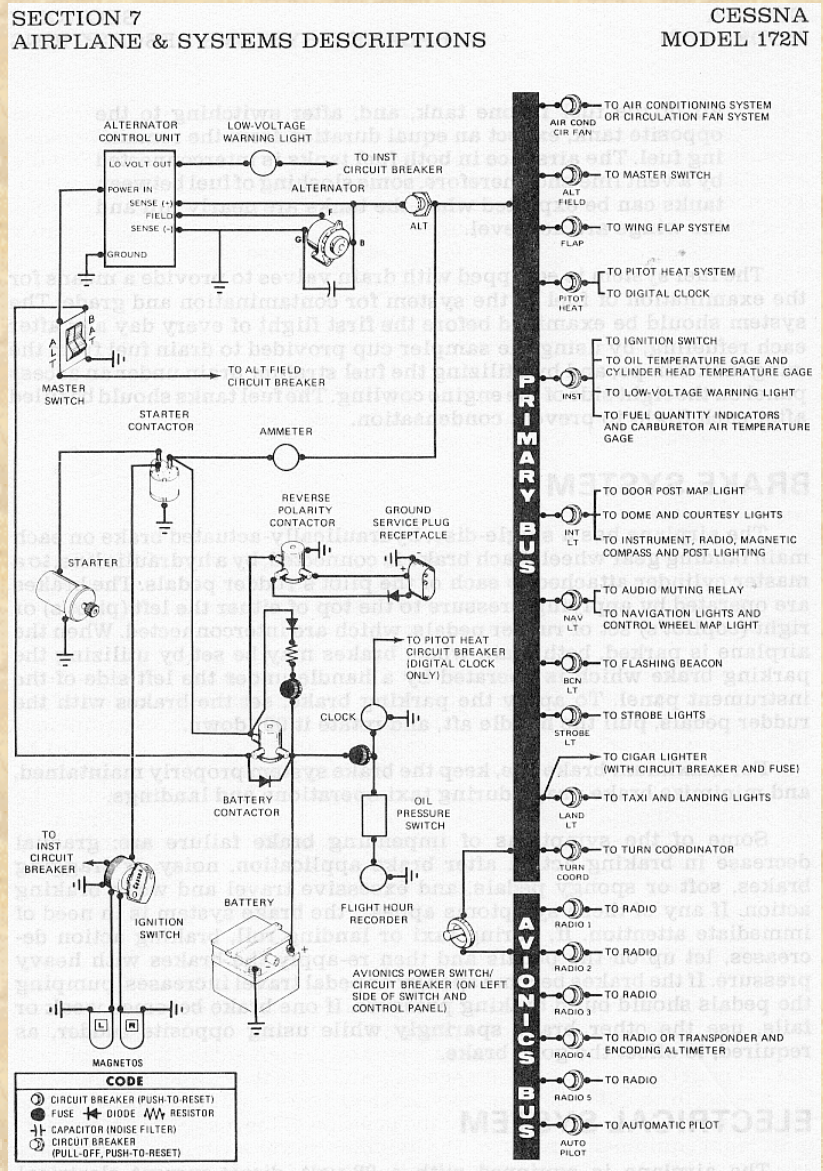


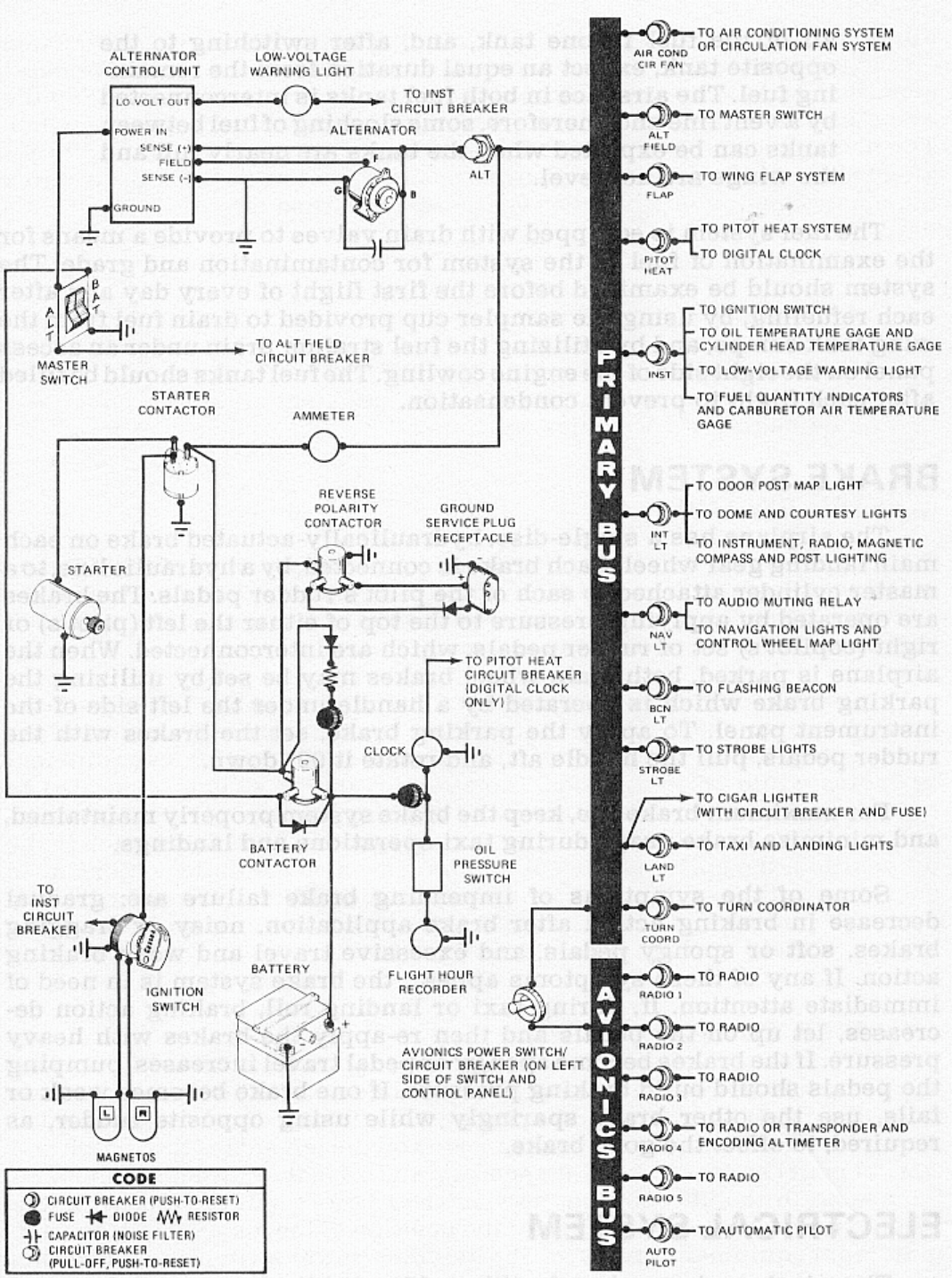


➢ Constant contact resistance as a result of precisely repeated crimp connection quality.

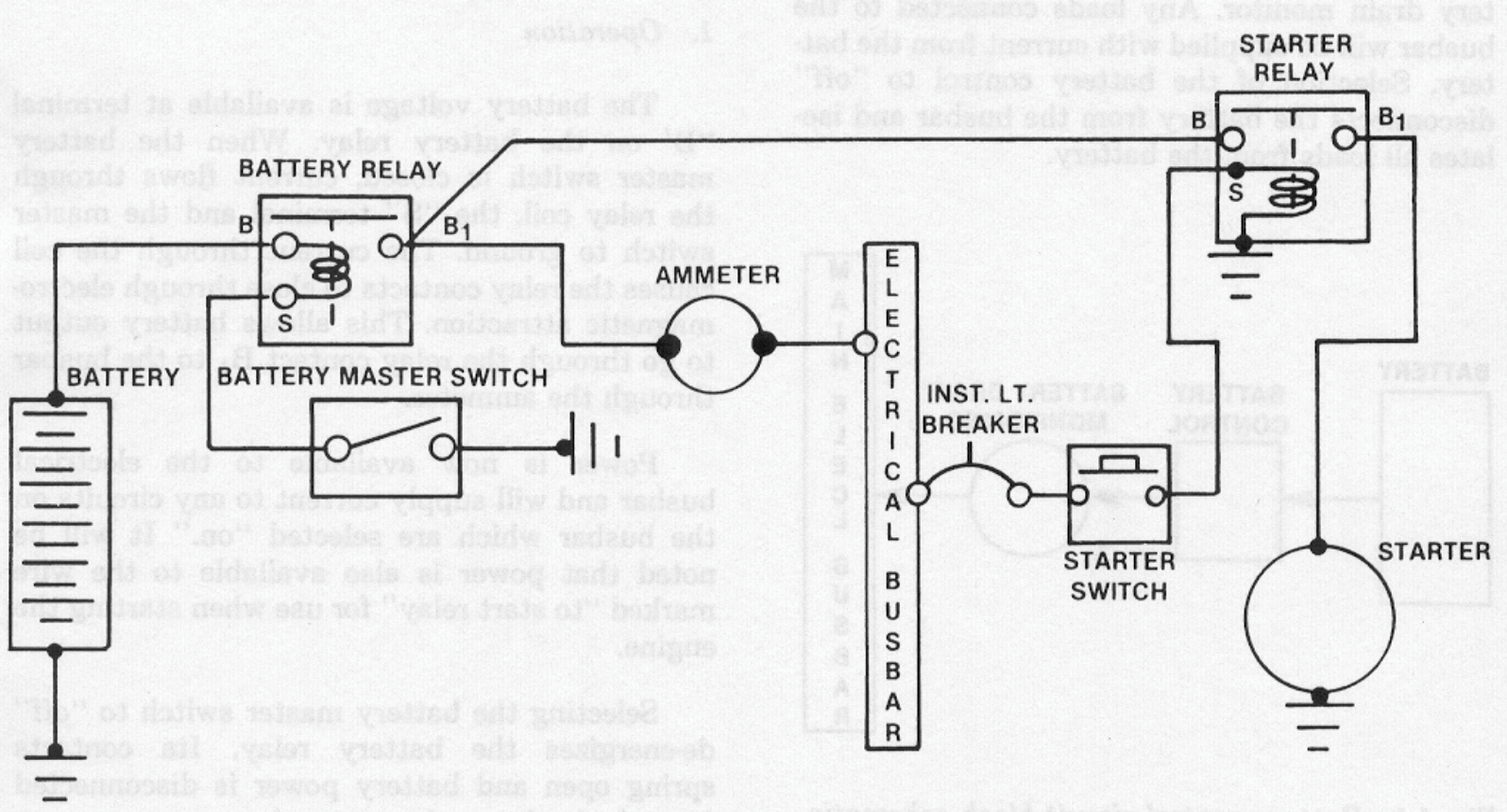
➢ Corrosion free connections as a result of cold weld action.

Aircraft Wiring Diagrams



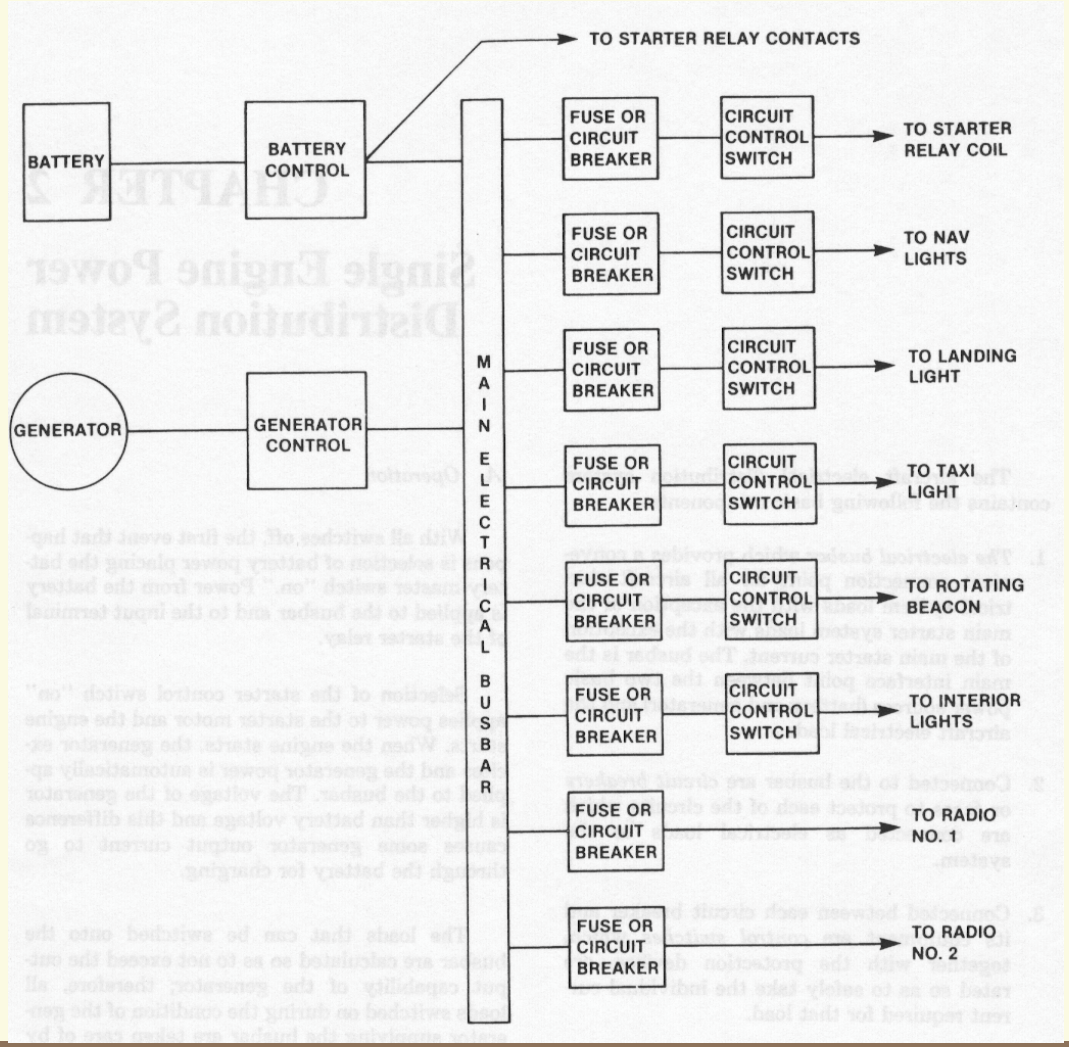

ALTERNATOR CONTROL UNIT
LOW-VOLTAGE WARNING LIGHT
TO INST CIRCUIT BREAKER
LO VOLT OUT
POWER IN
SENSE (+)
FIELD
SENSE (-)
GROUND
ALTERNATOR
ALT
F
G
B
MASTER SWITCH
TO ALT FIELD CIRCUIT BREAKER
STARTER CONTACTOR
AMMETER
REVERSE POLARITY CONTACTOR
GROUND SERVICE PLUG RECEPTACLE
STARTER
TO PITOT HEAT CIRCUIT BREAKER (DIGITAL CLOCK ONLY)
CLOCK
BATTERY CONTACTOR
OIL PRESSURE SWITCH
TO INST CIRCUIT BREAKER
IGNITION SWITCH
BATTERY
FLIGHT HOUR RECORDER
AVIONICS POWER SWITCH/ CIRCUIT BREAKER (ON LEFT SIDE OF SWITCH AND CONTROL PANEL)
MAGNETOS
CODE
CIRCUIT BREAKER (PUSH-TO-RESET)
FUSE
DIODE
RESISTOR
CAPACITOR (NOISE FILTER)
CIRCUIT BREAKER (PULL-OFF, PUSH-TO-RESET)
PRIMARY BUS
AIR COND CIR FAN
TO AIR CONDITIONING SYSTEM OR CIRCULATION FAN SYSTEM
ALT FIELD
TO MASTER SWITCH
FLAP
TO WING FLAP SYSTEM
PITOT HEAT
TO PITOT HEAT SYSTEM
TO DIGITAL CLOCK
INST
TO IGNITION SWITCH
TO OIL TEMPERATURE GAGE AND CYLINDER HEAD TEMPERATURE GAGE
TO LOW-VOLTAGE WARNING LIGHT
TO FUEL QUANTITY INDICATORS AND CARBURETOR AIR TEMPERATURE GAGE
INT LT
TO DOOR POST MAP LIGHT
TO DOME AND COURTESY LIGHTS
TO INSTRUMENT, RADIO, MAGNETIC COMPASS AND POST LIGHTING
NAV LT
TO AUDIO MUTING RELAY
TO NAVIGATION LIGHTS AND CONTROL WHEEL MAP LIGHT
BCN LT
TO FLASHING BEACON
STROBE LT
TO STROBE LIGHTS
TO CIGAR LIGHTER (WITH CIRCUIT BREAKER AND FUSE)
LAND LT
TO TAXI AND LANDING LIGHTS
TURN COORD
TO TURN COORDINATOR
AVIONICS BUS
RADIO 1
TO RADIO
RADIO 2
TO RADIO
RADIO 3
TO RADIO
RADIO 4
TO RADIO OR TRANSPONDER AND ENCODING ALTIMETER
RADIO 5
TO RADIO
AUTO PILOT
TO AUTOMATIC PILOT

Basic Starter Circuit

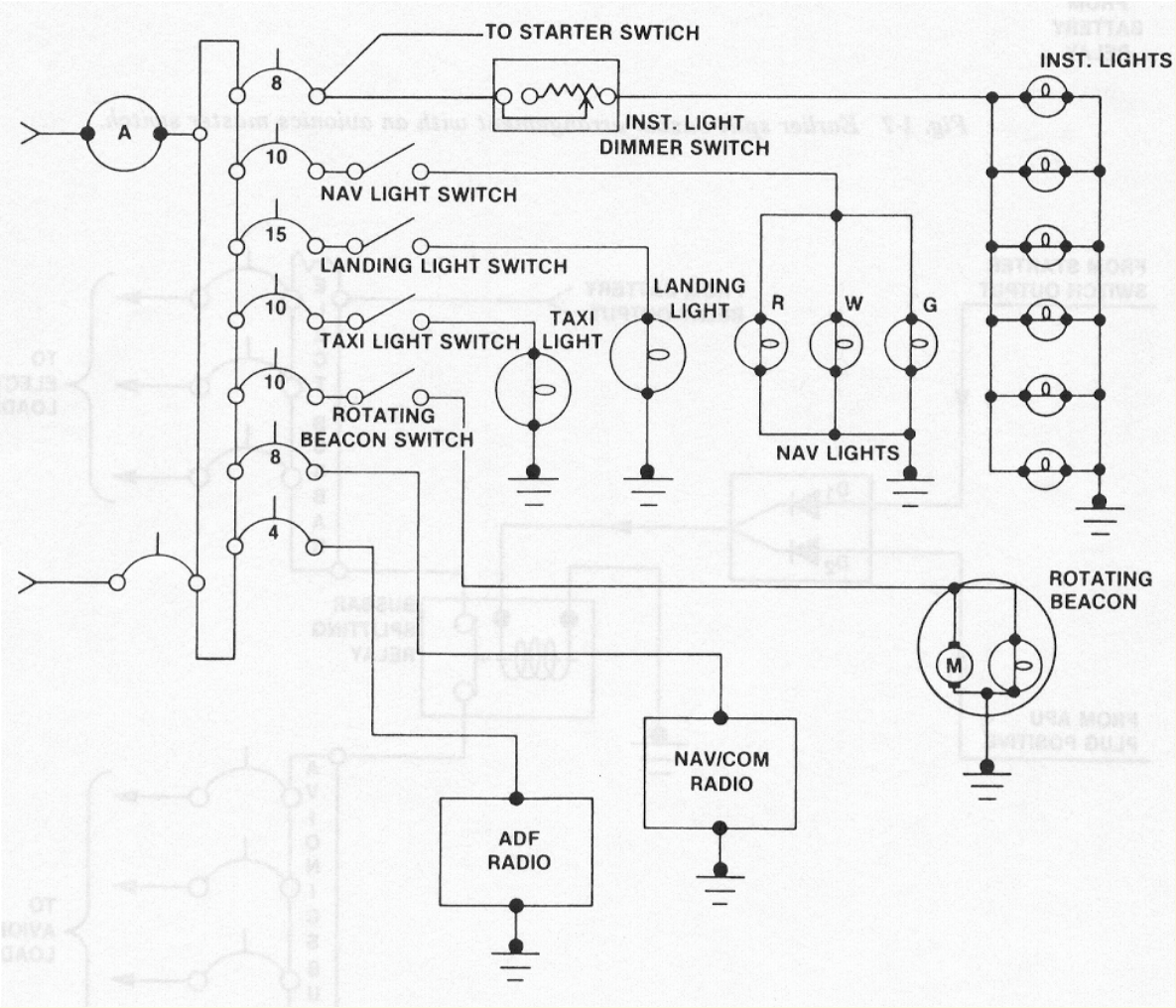


Battery Contactor

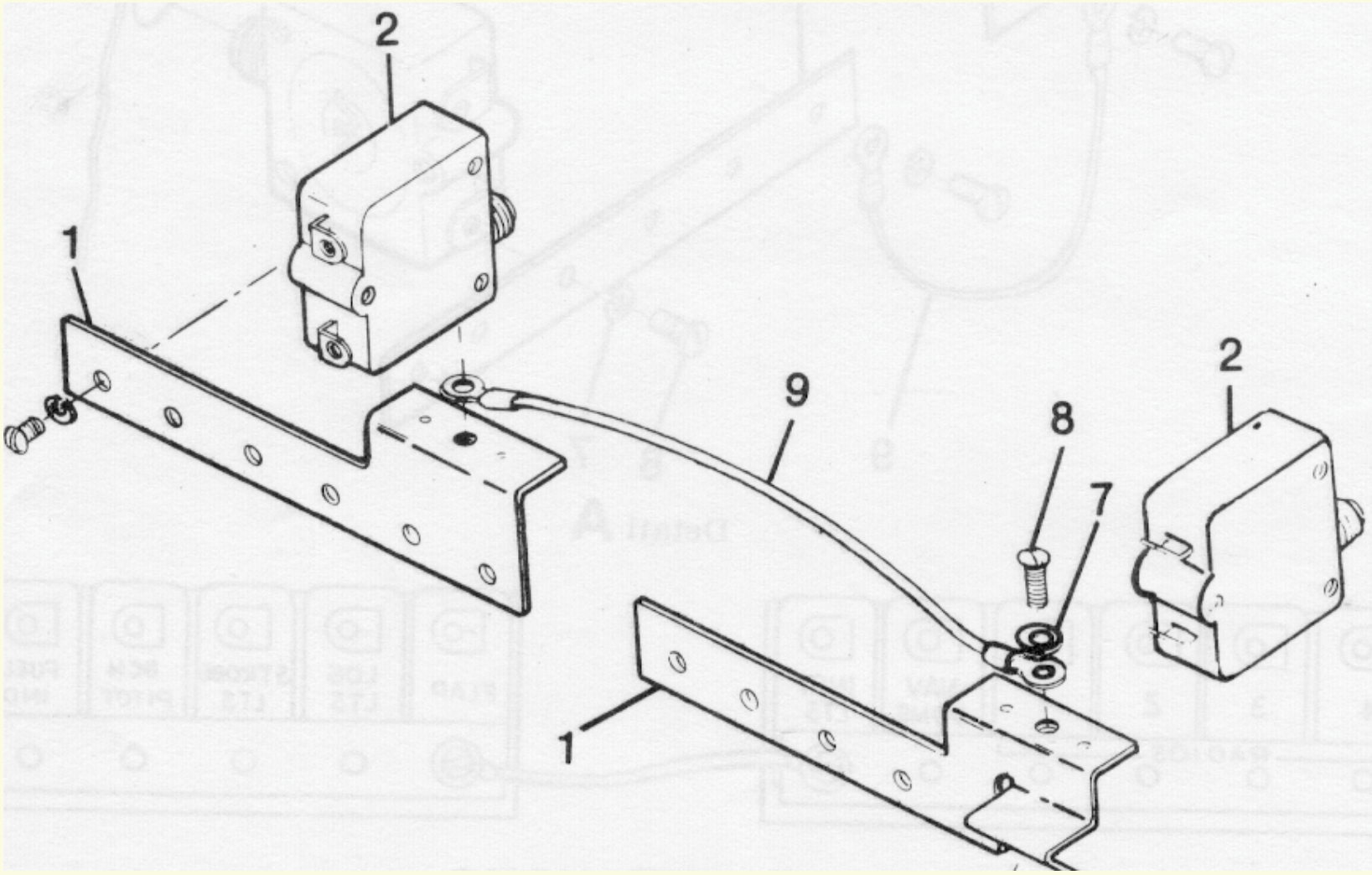
Basic Block Diagram



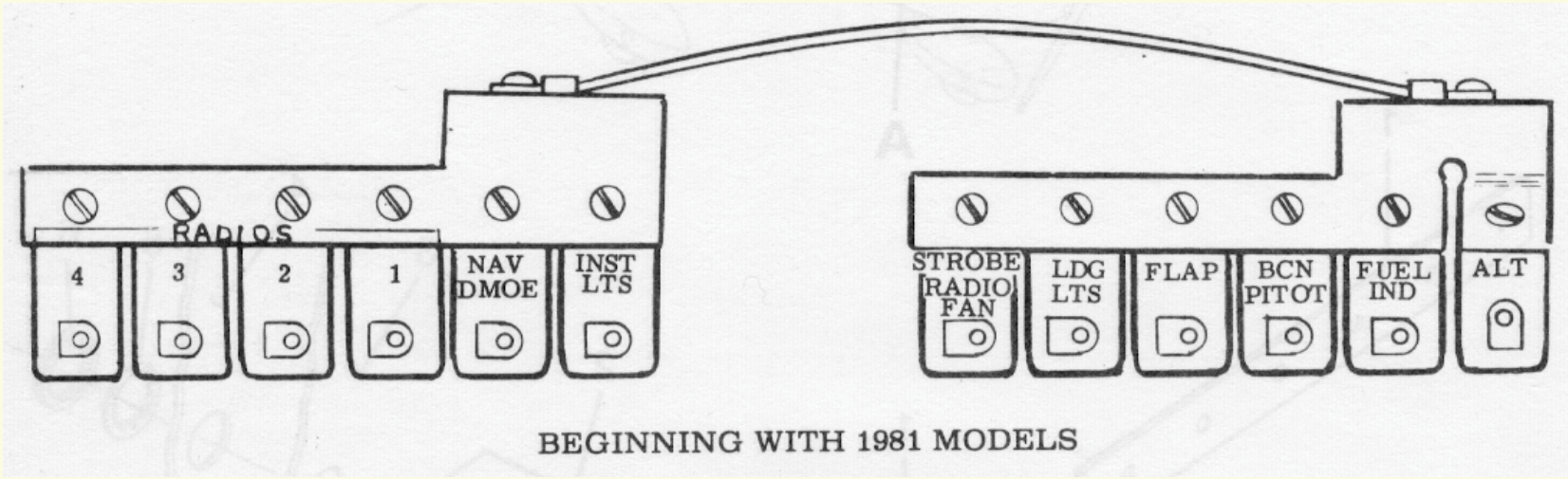
Power Distribution Diagram



Mechanical Bus-Bar Diagram

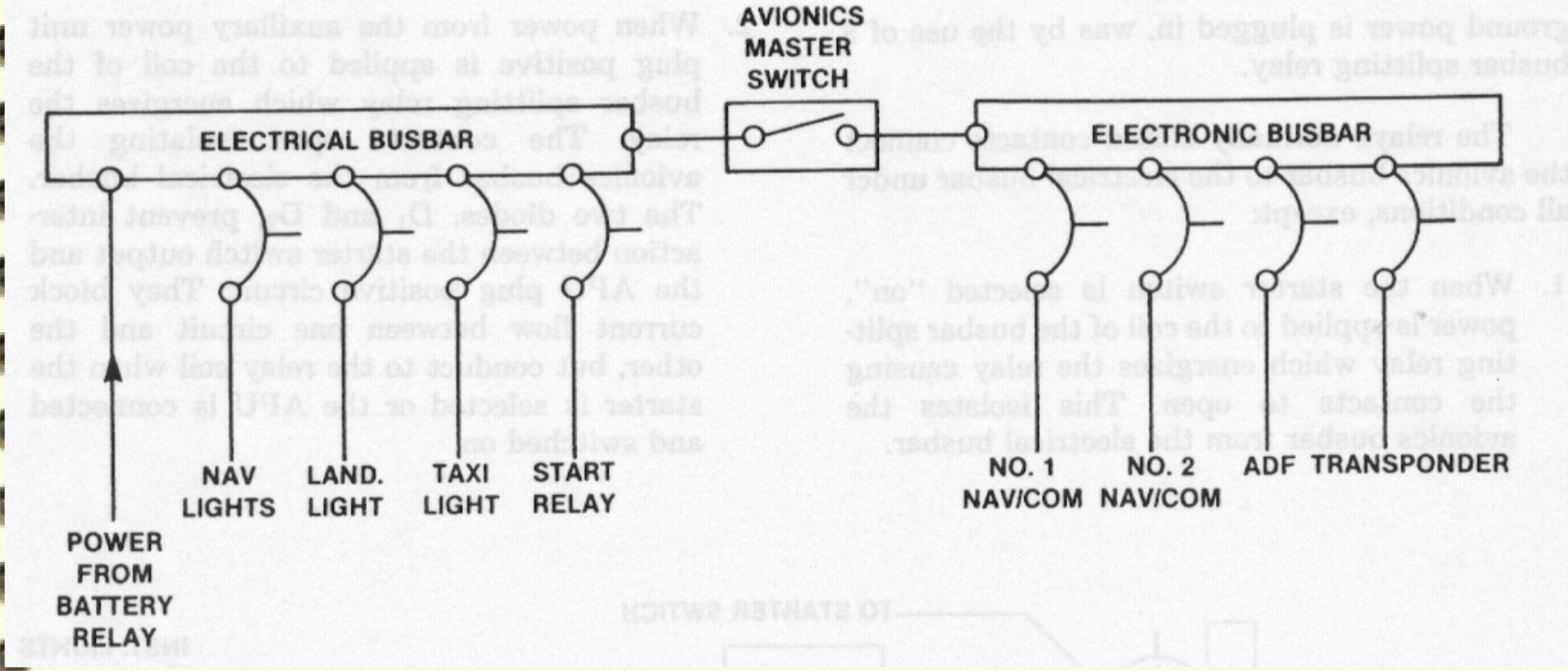


Circuit Breaker Configuration

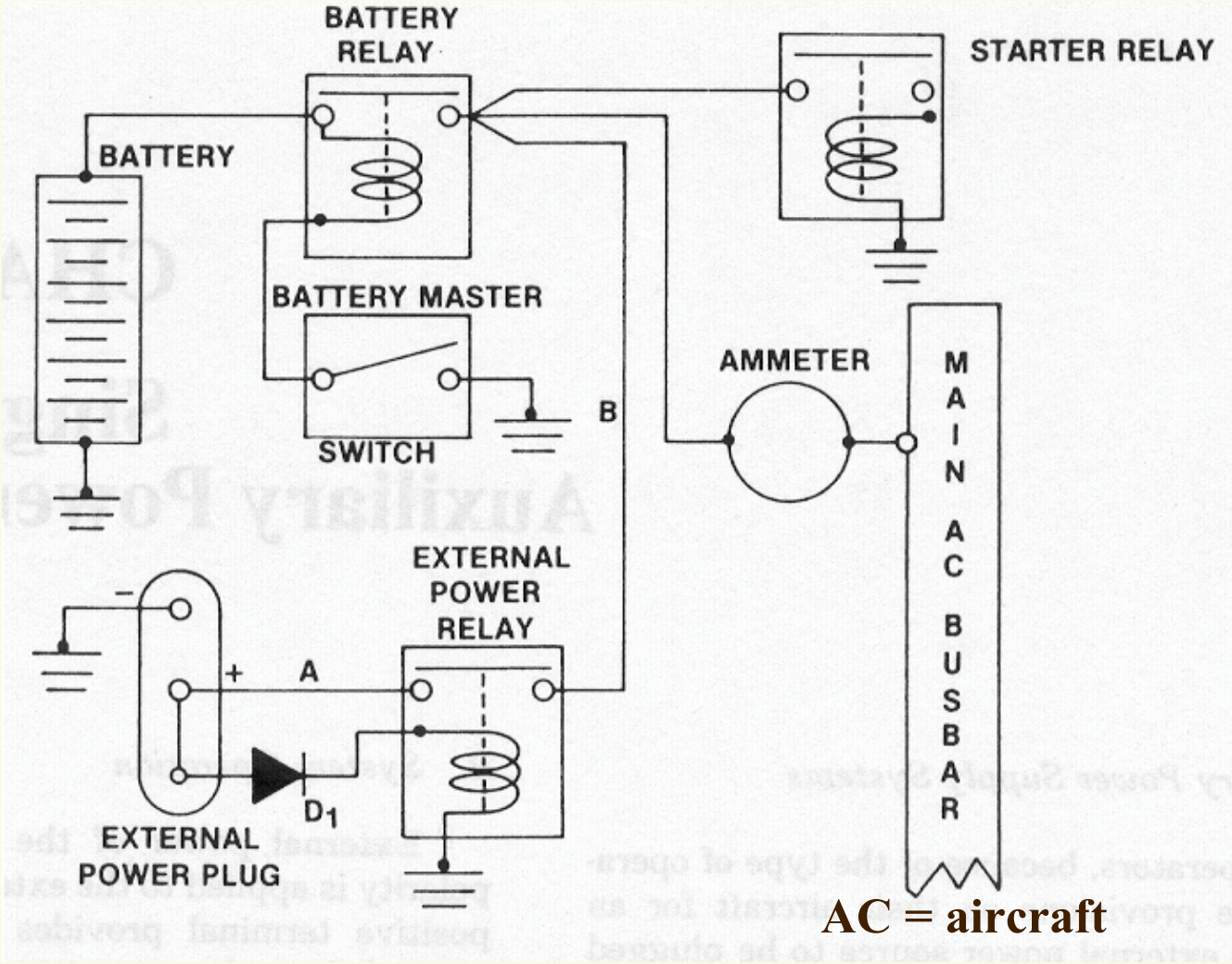


BEGINNING WITH 1981 MODELS

Switched Split-Bus Diagram

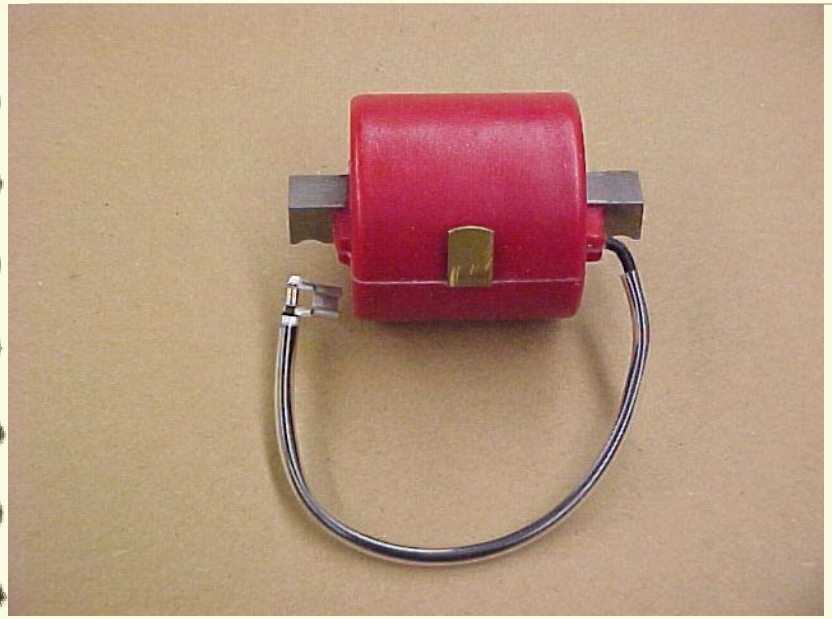


Polarity-protected Ground Power Circuit

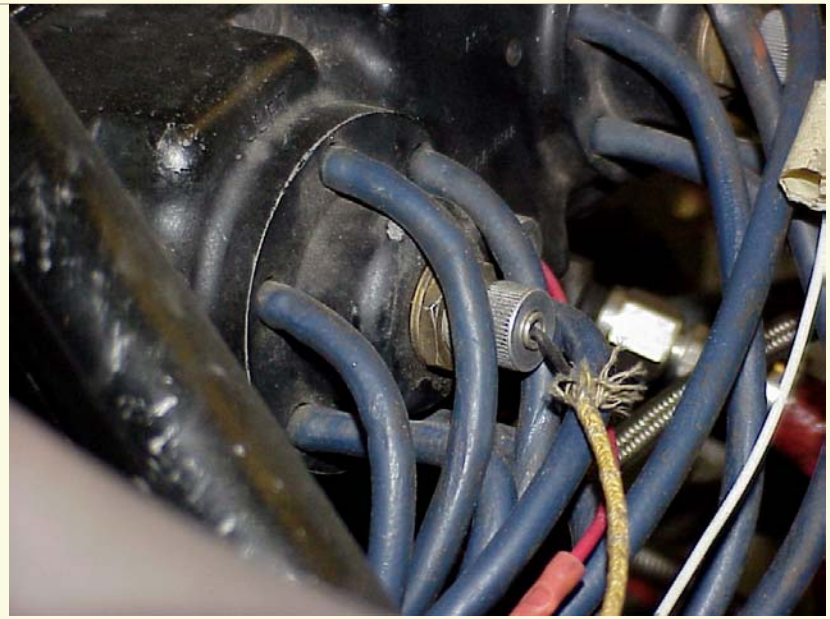


Magnetos

Magneto Components



Magneto Coil



P-Lead

Emergency Locator Beacon

Emergency Locator Beacon:
Failure Mode Analysis

✓ Dead Battery

(1) Because it has passed its expiration date

(2) Because it is defective (old TSO-C91)

✓ Failure To Activate

Defective “G” switch (old TSO-C91)

Emergency Locator Beacon

- ✓ FAR 91.207
- ✓ Battery replacement/recharge rules
  - When the transmitter has been used for 1 cumulative hour; or
  - When 50% of their useful life … has expired, as established by the transmitter manufacturer.
  - The new expiration date for replacing (or recharging) the battery must be legibly marked on the outside of the transmitter and entered into the aircraft maintenance record.

Emergency Locator Beacon

- ✓ FAR 91.207
- ✓ ELT must be inspected every 12 calendar months for:
  - Expired battery
  - Battery corrosion
  - Ability to transmit (since 1995 TSO-C91a)
- ✓ AIM 6-2-5
- ✓ On-the-air testing should be done only during the first 5 minutes past the hour.
  - No more than 3 audible sweeps.

Emergency Locator Beacon

- ✓ Newer ELTs use standard “D” cells.
- ✓ “Best If Used Before” date on batteries help, but you have to calculate when to replace the batteries based on 50% of dated life.
- ✓ For example, if you buy batteries with a dated life of 2008 in 2002, you must make a note to replace the batteries in 2005. (You can always put the batteries you take out of the ELT into your flashlight.)

Emergency Locator Beacon

- ✓ Original TSO-C91 1971
  - False alarm rate: 90%
- ✓ Current is TSO-91a 1985
  - False alarm rate: 5% (primarily due to redesigned “G” switch)
- ✓ Not required to upgrade to a 91a unit if an exact replacement for a 91 unit can be obtained.
- ✓ TSO-91/91a to be phased out by Feb. 1, 2009 and replaced by TSO-126.

Emergency Locator Beacon

- TSO-91/91a Specifications
  - Amplitude modulation (AM)
  - 50 to 100 milliwatts (0.1 watt)
  - Should be able to transmit continuously for 48 hours (minimum)
  - Transmits on 121.5 MHZ and 243 MHz
  - Accuracy: 12 miles
  - Time to locate: 2 passes (up to 3.5 hours)

TSO-91a panel-mounted control

Emergency Locator Beacon

- TSO-126 Specifications
  - Digital modulation
  - 5 watts
  - Should be able to transmit continuously for 48 hours (minimum)
  - Transmits on 406 MHz
  - Accuracy: 2 miles (100 meters with GPS data)
  - Time to locate: 1 pass
  - At this time TSO-126 ELTs are ***not*** required in any aircraft flying in the United States.

What Can Go Wrong?

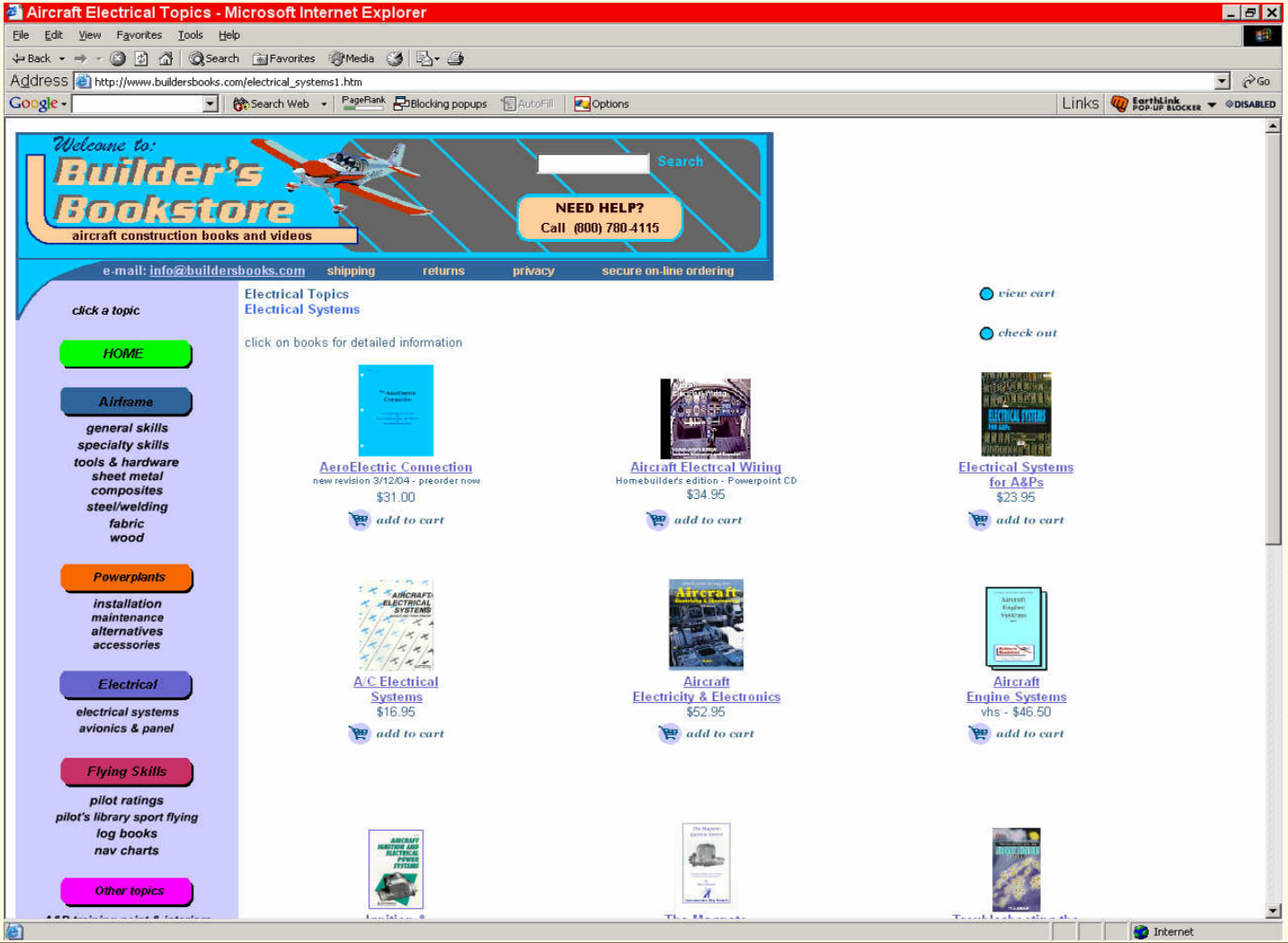
- AOPA ***Pilot*** Magazine, October, 2002
  - "Never Again" (B-25 with water-soaked magneto harness)
- ***Aircraft Systems: Really knowing your airplane*** by Richard Taylor (1991)
  - Belvoir Publications ISBN: 1-879620-04-9

To Learn More

Web Site: www.aeroelectric.com

AeroElectric Connection - Aircraft Electrical Systems - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites Media
Address http://www.aeroelectric.com
Google Search Web PageRank Blocking popups AutoFill Options Links EarthLink POP-UP BLOCKER DISABLED
The AeroElectric Connection
6936 Bainbridge Road
Wichita, KS 67226-1008
Fax/Phone: 316-685-8617
Click here to contact Bob at AeroElectric Connection
Site Index:
Publications & Avionics From AeroElectric Connection
What's New
Tools and Materials From B&C Specialty Products
AeroElectric List (On-Line Consulting)
Downloadable Reference Materials
FAA Issues
Radio Pinout Guides
Weekend Seminars
CD_Rom Download
Done
Internet

Web Site: www.buildersbooks.com



To Learn More

To Learn More

- ***Aircraft Electrical Systems: Single and Twin Engine*** by J. E. Bygate (1990)

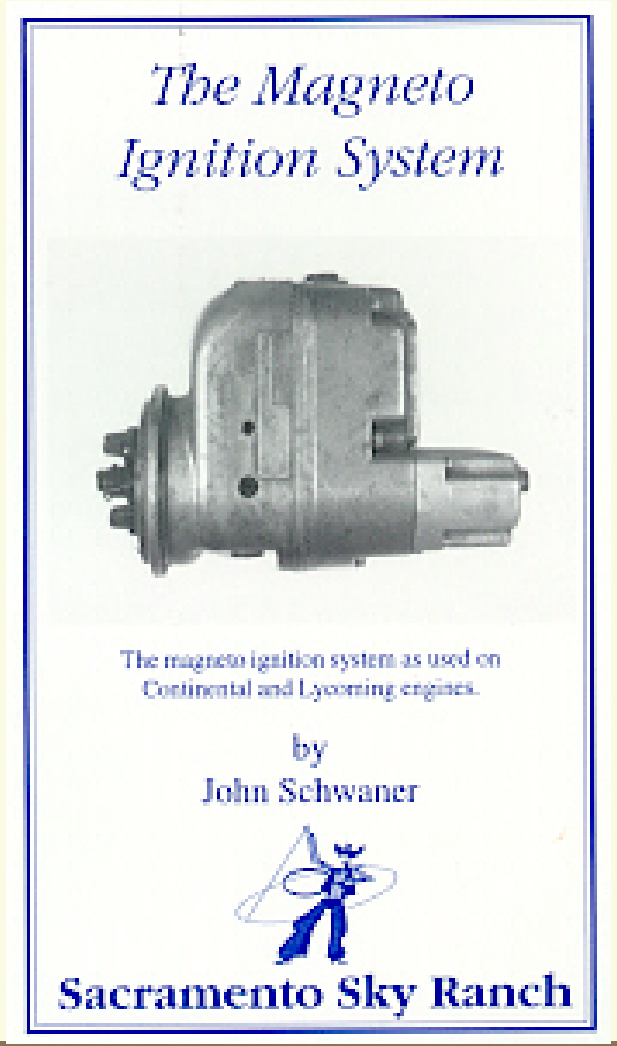
  (Jeppesen Sanderson Training Products)

  ISBN: 0-89100-357-6
- Kitplanes Bookstore

  http://kitplanesbooks.com

  Good selection of books on all subjects

To Learn More



To Learn More

- ***The Magneto Ignition System***
  by John Schwaner
  (Sacramento Sky Ranch)
  ISBN:
- Kitplanes Bookstore
  http://kitplanesbooks.com
  Good selection of books on all subjects

To Learn More

- **Aviation Consumer**
- **www.aviationconsumer.com**
- **$36 for 6 issues**

February, 1995 issue

"No Juice: Batteries don't have TBOs"

December, 2003 issue

"Battery Buying Advice"

January, 2004 issue

"Aviation Battery Shootout"

To Learn More

- **Light Plane Maintenance**
- **www.lightplane-maintenance.com**
- **$19.97 for 6 issues**

December 2003 issue

"(Battery) Capacity Testing"

January, 2004 issue

"Battery Testing"

To Learn More

Published by:

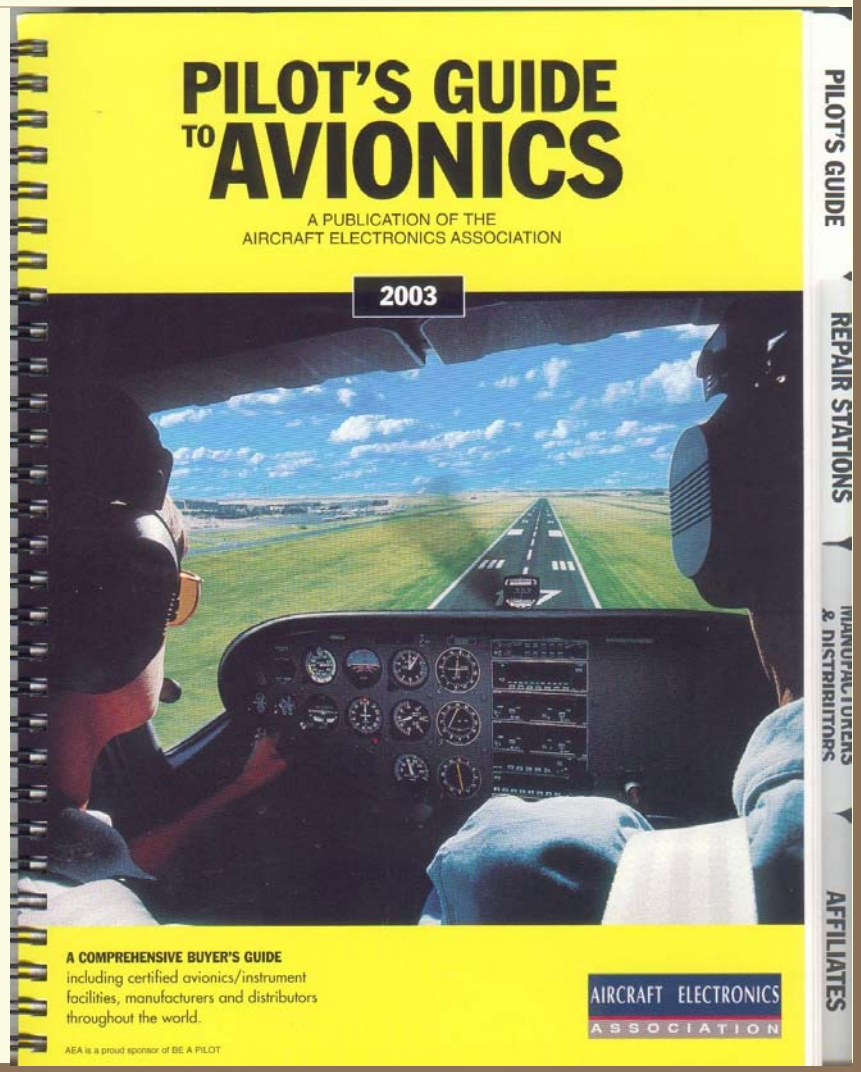
Aircraft Electronics Assoc.

(Free)

Call 816-373-6565

or email

ritaa@aea.net


PILOT'S GUIDE TO AVIONICS
A PUBLICATION OF THE AIRCRAFT ELECTRONICS ASSOCIATION
2003
A COMPREHENSIVE BUYER'S GUIDE
including certified avionics/instrument facilities, manufacturers and distributors throughout the world.
AIRCRAFT ELECTRONICS ASSOCIATION
AEA is a proud sponsor of BE A PILOT
PILOT'S GUIDE
REPAIR STATIONS
& DISTRIBUTORS
AFFILIATES

Thank You!